Fall 2015

The Modern Grounds Maintenance Worker

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by

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A report submitted in partial fulfillment of the
requirements for the degree of

Master of Science
Industrial Hygiene Distance Learning/Professional Track

Montana Tech of the University of Montana

2015

Abstract

More than 1 million workers are employed in Grounds Maintenance operations in the United States today. These workers perform varied but recurring tasks necessary to maintain the orderly and healthful function of parks, residential and commercial landscapes, and institutional grounds.

Technological advancements in machinery have, over time, vastly increased the productive impact of each worker. While fewer workers are needed per acre, the same advances in production have amplified some types of health risk to this work population.

This inquiry identified the primary chronic stressors inherent in modern grounds maintenance work, chiefly exposures to noise and respirable engine emissions.

The results reveal a number of conditions of concern, and support a strong need for awareness training and control options for this population and its managers in order to reduce risk of chronic adverse health effects.

Keywords: Noise, Carbon Monoxide

Dedication

I would like to thank my wife for her patience and unwavering support while I pursued the IH MS program. I also owe an enormous thanks to my Mom and Dad, who for my full lifetime have always been first to encourage diverse learning experiences, academic and otherwise.

Acknowledgements

I would like to thank my colleagues at MSU Safety & Risk, past and present, for their professional support and counsel, as well as the faculty at Montana Tech for their devoted experience in not only the objective science of IH, but especially in methods most useful to IH application in industry.

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where:
F(e) = The equivalent noise exposure factor.
T = The period of noise exposure at any essentially constant level.
L = The duration of the permissible noise exposure at the constant level (from Table D-2).

Glossary of Terms

Action Level	exposed at or above an 85 dBA (TWA) in A-scale
Administrative Controls	methods enacted to limit exposures through adjustments in scheduling
Area Sampling	measurement made in the immediate area of the source, representing the local exposure
Attenuation	reduction of noise exposure through time, distance, and/or shielding
Audiologist	professional who specializes in hearing function and rehabilitation; American Speech, Hearing and Language Association
Baseline Hearing Test	initial measurement of hearing ability used in comparison to future hearing tests
Carbon Monoxide (CO)	colorless, odorless, tasteless gas with a well-known toxicity to humans
Continuous Noise Exposure	exposures measured constant at a given level during a given time period
COHb	Carboxyhemoglobin
Criterion Sound Level	sound level at 90 for OSHA, and a level of 85 dB for ACGIH
Decibel (dBA)	unit of measured of sound level corrected to the A-weighted scale; ANSI S1.4-1977
Ear Muffs	Devices worn over the ears to attenuate noise exposure
Ear Plugs	Devices worn inside the ear canal to attenuate noise exposure
Engineering Control	deliberate preventative effort to engineered a physical change to the exposure environment, in order to eliminate, shield, remove, or isolate an exposure source
GLGE	Gasoline powered Lawn and Garden Equipment
GLME	Gasoline powered Landscape Maintenance Equipment
Audiometric Exam	measurement test which seeks to establish employee hearing threshold level as a function of frequency
Hertz	units of measurement frequency; equivalent to cycles/ second
Noise Area	defined region where sound levels may equal or exceed Action Level

Noise Dosimeter	specialized sound level meter which measure the collective noise exposure over a period of time
NIHL	Noise Induced Hearing Loss
Ototoxic	exposures to drugs or chemicals which result in damage to hearing, balance, or both
Potentiation	enhancement of one agent by another so that the combined effect is greater than the sum of the effects of each one alone
PM	particulate matter
PPE	Personal Protective Equipment; may include ear plugs, face shields, hard hats, eye protection, etc. Specified based on the recognized hazards present
Representative Exposure	measurements of a sample employee's 8-hour (TWA) sound level which is able to applied as a reasoned representative exposure of other employees conducting similar operations
Sound Level Meter	instrument for the measuring sound levels
SI	spark-ignition; distinct from compression ignition engine design
Standard Threshold Shift	a change in hearing threshold ability when compared to baseline hearing measurement, using averages of 10 dB or more at 2000, 3000, and 4000 Hz
String Trimmer	tool with a rotating cutting head and flexible monofilament line which cuts grass and weeds in areas too small or difficult to detail with larger mowing machines
Time Weighted Average (TWA)	an exposure dose which has been weighted for an assigned time duration, typically used as an 8-hour TWA

1. Introduction

Grounds Maintenance work occupies a unique niche within the workplace, as the majority of Americans have at least a small amount of personal work experience with it themselves. In this country, it is nearly universal for the average homeowner to have a powered lawnmower, and many of these homes may also have a variety of associated powered tree, bush, or weed trimmers. "Yard work," as it is commonly described in the residential setting, occupies the weekend hours of millions of Americans, and is often promoted as a form of exercise, an opportunity for fresh air, and a way to commune with nature.

While it is straightforward to establish that the American public is at least generally aware of this type of maintenance work and the tasks involved, it is also evident that very little public acknowledgement exists of the chronic hazards associated with the professional's version of the trade. The professional worker is tasked with completing similar work, sometimes even using similar tools, but at significantly extended durations of 40 or more hours a week. This intensive increase in work duration results in workers exceeding published limits on permissible exposure (Bunger, 1997). The lack of awareness to these stressors, in light of breaching established exposure thresholds, and the according potential for permanent disability, creates a potential for hazardous conditions (Owens; Evans; Hook; 2015).

The Occupational Safety and Health Administration (OSHA) was established in 1971, and was tasked with a broad duty to provide for safe working environments through training, outreach, education, and assistance. While some of the hazards inherent to grounds maintenance work are the subject of OSHA guidance and permissible exposure limits, a specifically addressed standard which speaks to the nature and hazards of grounds maintenance work does not exist. OSHA's General Duty clause, requiring that employers "maintain a workplace free from recognized hazards that are causing or are likely to cause death or serious physical harm" only peripherally covers the grounds maintenance profession.

These conditions persist on a daily basis among the professional workers and managers within the grounds maintenance industry itself (Owens; Evans; Hook; 2015). In 2015, a collaborative effort between Montana State University (MSU) office of Safety & Risk Management and MSU Grounds Maintenance staff worked to assess the extent to which this work population may be at risk of chronic adverse health effects related to their assigned tasks.

2. Background

Montana State University is a public, land-grant university located in Bozeman, Montana. The main campus at MSU- Bozeman has existed on its current site for more than 120 years. Dedicated grounds maintenance personnel have been in place nearly that full duration. The campus contains extensive ornamental landscapes, hundreds of acres of planted turf grass, and many thousands of trees. MSU grounds maintenance staff currently utilize modern tools and methods to complete this maintenance work, and it is recognized that this intensive reliance on machinery may put the grounds maintenance staff at risk.

The first grounds maintenance employees at MSU would have most likely been first and foremost farm laborers. These early era employees, within that trade, would typically already be well familiar with the endemic hazards of farm work. Simply conducting the farm tasks at hand served to provide the constant feedback necessary for one to gain an ingrained understanding of how to complete the necessary work with a minimum of injury. Some farmer laborers in that time certainly suffered acute and chronic disease as a result of workplace hazard (Reinhart, 2003), but the nature of the stressors of that time were primarily confined to those usual hazards they already knew well: soft tissue injuries, musculoskeletal disorders, heat and cold stress, sunburn, insect bites, etc. Early era tool use relied extensively on each worker’s effort to perform the cutting action, as illustrated in Figure 1.

Figure 1: Cutting with Scythe (Belgart, 2014)

As society's collective wealth grew, a growing need for maintaining parks, grounds, and planned landscapes developed. The concurrent advance of mechanized labor with the applied utility of the small combustion engine helped to nurture cultural interest in maintaining the lawn & grounds surrounding both public and private buildings.

2.1. Mechanization

Grounds maintenance tasks are typically repetitive by nature, where a worker may perform cutting or trimming on the same sites on a weekly, monthly, or seasonal basis. Grounds Maintenance managers quickly realized a dual benefit to employing power tools, as productivity per acre increased, and the inherent challenges of managing a large labor force (staffing problems, sick days, inconsistent work ethic, etc.) were thereby decreased (Micentic 2015). The subsequent shift toward reducing labor through increased reliance on machinery was accompanied a parallel shift in the predictable occupational ailments. Over time, the common workplace injuries began a permanent retreat from the soft tissue injuries endemic to manual labor, to one defined by the physical and chemical stressors related to mechanized tool use, primarily through noise, vibration, and inhalable engine emissions.

Figure 2: Advertisement illustrating the advance of labor saving machinery

As the public availability for labor saving machinery to help maintain public and private landscapes increased (Figure 2), a concurrent shift in the occupational health risk to the full-time grounds maintenance worker moved with it. While the shift to mechanization occurred over decades, the anticipation and identification of these hazards has been slower to advance (Bunger, 1997). The new chronic hazard categories are now becoming increasingly recognized among occupational health researchers to be hearing loss, nerve damage, and diseases to the blood and primary organs (Mallick 2009; Heaton, 2011; Bunger, 1997, Clapp 2008).

2.2. The Modern Tools

As machinery advanced, the public's appetite for manicured landscapes grew along with it. The scope of work for grounds maintenance has been increasingly shifting from what was originally a primarily "maintenance" based attention, and instead now trends toward a "manicure" level of landscape grooming. As this has happened, the variety of available tooling increased significantly. Large commercial maintenance companies and institutional departments may have 10 or more mower sizes to choose from within their own fleets, ranging in cutting swath from 18 inches to over 16 feet in a single pass.

Changes have not entirely been driven by production or acres mowed per day. Increasingly, the industry that once relied on the scythe, hand rakes, brooms, hand saws, and a tolerant public, now serves a demanding public taste for manicured landscapes. Powered options have increased to include the following handheld tools with spark combustion engines:

- String Trimmers
- Clearing Saws
- Brush Cutters
- Pole Saws
- Chain Saws
- Edgers
- Blowers
- Hedge Trimmers

The manufacturers of these tools have typically favored two stroke engines for their durability, low relative cost, and very high power-to-weight ratio. Within the past 10 years, 4-stroke models are now common, although the benefits of 2-strokes still maintain a significant place in the commercial and institutional workshop. The professional's selection of powered hand-held grounds maintenance tools includes 21 different models of chainsaws, 13 different models of string trimmers, 17 different models of hedge trimmers, 9 different blowers (Stihl Pro. 2015). This tool offering is from one manufacturer alone.

2.3. The Modern Workday

The evolution of production progression and related shift in the nature of workplace hazards occurred over more than 100 years, and multiple generations. These increases in production, made generally through increases in horsepower and allowable noise level have been balanced on what the human operator would consent to endure. The achieved "consent" to endure these stressors has been brokered generally through the offerings of personal protective equipment (PPE), yet whether this control is truly effective or not remains a matter of opinion. Federal standards related to the 1972 Consumer Product Safety Act may guide manufacturers to balance noise levels to be at least theoretically within a protectable range. OSHA itself is less confident in the attenuation possible through hearing protection devices (ear plugs, muffs, etc) in a field setting (OSHA Appendix IV-C 2015).

With that understood, the modern workday of a maintenance worker involves a constant interaction with noise. In most cases, production is not occurring if noise is not present. Notwithstanding worker travel to and from a site, some forms of equipment repair or fueling, or the generally brief consideration of work strategy, the grounds maintenance production environment is bonded definitively to the generation of noise.

Recognizing that the typical work environment contains significant physical and chemical stressors, including a wide variety of powered tools with exposed cutting surfaces and limited guarding, thermal stresses, intense vibration, thrown objects, near-constant elevated noise, presence of chemicals including pesticides, fuels, oils, and engine exhausts, it requires a complex and shifting ranking of hazards at any given moment.

For the purposes of this report, recognition is given to these mentioned established hazards as legitimate each in their own consideration as an assessment of safety within the trade.

3. Anticipated Health Effects from Typical Work

Occupational hazards related to grounds maintenance work have identified elevated levels of noise, vibration, and chemical inhalations as common and universally present exposures (Volckens 2007; Heaton 2011, Murphy 2007).

With powerful machinery performing cutting operations occurring in constantly variable weather and site conditions, it is well understood that there are a multitude of opportunities for injury in this work. Job hazard evaluation and safety trainings were conducted with grounds maintenance staff at Montana State University-Bozeman in 2014 and 2015. Discussions with grounds maintenance staff and managers assisted in the prioritization of potential for both acute and chronic injury. Certainly other occupational categories rank higher on a severity scale in terms of fatalities or very serious injury, yet the pure high percentage of production hour conditions with high physical injury exposure and/or threshold exceeding hazard is difficult to find in many other trades (R. Evans; E. Hook; personal communication, MSU 2015).

3.1. Acute vs Chronic Hazard

According the Bureau of Labor & Statistics, grounds maintenance workers earn a median average of $11.53 an hour (bls.gov 2012). For the line employee, this is a work category which contains few barriers to entry. No formal education is typically required, workers need not speak much or any English, and most if not all training is conducted on the job (Owens, 2012). Because of these circumstances, and with acknowledgement of the aforementioned identified hazards, it is likely that the typical worker is relatively unaware of any hazards other than those readily observable to an untrained worker.

The objective of this IH report is to characterize the chronic noise and equipment emission hazards related to grounds maintenance at a university campus.

3.2. Selection of Sampling Focus

An observation of the broad scope of grounds maintenance work at MSU quickly reveals a populous list of potential stressors, primarily those in the physical, chemical, and ergonomic categories. Notably, this study attempts to identify and evaluate those hazards that are (A) less obvious due to the presence of assumed (though unverified) control through PPE use of ear protection, and (B) chemical inhalation hazard whose exposure remains under-recognized and largely uncontrolled. The hazards identified for this work population as most significant in terms of chronic exposure consequence and potential for permanent disability. For those reasons, and with gained context within a relevant literature review, sampling was further narrowed to an assessment of the exposures to assess levels of noise and present concentrations of carbon monoxide.

3.3. Speed over ground: the selection of handheld equipment vs. mowing equipment potential for exposure potential

Although it is readily acknowledged by both workers and manufacturers that carbon monoxide is one of the major recognized toxicants present at varying levels in engine exhaust, it is the **actual job practice difference which creates the highly hazardous conditions in handheld tool use**.

The distinction is that mowing machines move relatively quickly into new and fresh airspace constantly while they are in motion. Handheld tool operators do not enjoy this benefit. By contrast, operators of brush cutters, hedge trimmers, and leaf blowers generally move slowly, and in the case of pole saws and chain saws, operators rarely move much at all during operation. In practice, the slow speed of movement does not overcome the confines of a growing exhaust plume, so the operators of handheld equipment are typically working within the plume whenever they are in production. It is hypothesized that the speed over ground covered is what separates a tolerable exposure from one that can significantly exceed permissible and recommended limits for inhalation exposure. Except in conditions where natural wind can overcome the exhaust production, the operators may potentially be exposed to significant the engine exhaust emissions.

In practice, the two concerning exposures, elevated noise and a present exhaust cloud, define the consistent workspace conditions of the engine powered handheld tool user. The noise follows the operators everywhere, with point sources generally sub-meter from the ears, and the cloud of exhaust toxicants is large enough, and movement slow enough, for the operator to rarely escape the elevated exposure conditions.

4. Literature Review

A literature review was performed to develop context of past research into the combination of elevated noise conditions at extended durations, and especially to assess the background of research related to small engine exhaust emissions.

Past studies performed by a group of Swedish researchers ought to determine the chemical composition and mutagenicity in particles from chainsaw exhaust (Magnusson 2010). A 2010 study isolated one model of chainsaw and two targeted fuels with attempts to capture and compare levels of chemicals known or suspected to be upper respiratory and eye irritants. Among the compounds identified: formaldehyde, other aldehydes, nitrogen oxides, hydrocarbons, carbon monoxide, as well as evidence of mutagenic polycyclic aromatic hydrocarbons (PAH's) (Magnusson, 2010).

The study revealed a reproducible method for consistently qualifying and quantifying particulate levels and gas concentrations with handheld two-stroke chainsaw engines, and the authors reported significant PAH emission levels when different fuels were used (Magnusson 2010).

An earlier German study evaluated the broader context of chainsaw exhaust and exposure potential by personal air monitoring of carbon monoxide and blood concentrations of carboxyhemoglobin (COHb) (Bunger 1997). This study examined exposure levels using real-world field conditions with 14 professional chain saw operators.

Of particular note, the study used video recordings during actual logging operations to chart movement of exhaust gases. Using two cameras at right angles to each other, a three dimensional image of the exhaust cloud was assembled. Observations reported: "contrary to expectations, the hot exhaust was not immediately swept upwards by thermal lift, but remained close to the ground and floated away in the direction of the wind. This exposed all loggers performing tasks in a leaning or squatting position" (Bunger 1997). This study reported that the TLV "was repeatedly exceeded during the performance of all tasks, with maximum levels >500ppm recorded in isolated cases" (Bunger 1997).

Small engines are widely recognized as major sources of airborne particulates (Banks, McConnell 2015). An additional small-engine focused review, the Environmental Protection Agency (EPA) in 2012 recognized a need for more extensive review of two-stroke engine exhausts, and sponsored research to characterize emissions from small gasoline non-road engines rated below 19 kilowatts. This study focused on the string trimmer, ranked after the lawn mower as the second most common small gasoline non-road application in the United States (Gabele, EPA 2012). In particular, this study concluded that the examined engines and measured exhausts were significantly affected by:

- Fuel selection, making distinctions between baseline 1990 formulation gasolines (RFA) and re-formulated gasolines (RFG) with adjusted olefin and aromatic constituent levels.
- Emission rates were extremely sensitive to air/fuel ratio, which the study acknowledged will change as an engine is operated for extended periods.
- RFG emissions resulted in sharply lower benzene levels, but somewhat higher formaldehyde levels.
- Particles collected were predominantly sub 2.5 micron in diameter.
- Composition of organic emissions resembled composition of the fuels more than with 4-stroke engines.

The study makes clear that the stated intent of the EPA assessment was driven by an effort to evaluate and potentially provide data to support legislated standards seeking reductions in hydrocarbons and nitrogen oxide levels as a means of reducing mobile source emissions for ozone affecting compounds. The primary objective of the EPA assessment assess compliance with the National Ambient Air Quality Standard (NAAQS).

In light of the extensive study parameters necessary for complex exhaust evaluation, a decision was made to avoid a sampling effort assessing the numerous toxicants present in emissions. Instead, a more realistic approach was necessary given the limits of time and resources, especially with a goal of gathering actionable results for outreach awareness. From this perspective, the study was again re-focused to limit sampling to raw operator inhalation zone carbon monoxide levels and operator ear-level measured noise levels from (12) separate handheld spark-ignition tools.

4.1. Regulatory Standards for Noise

The regulatory environment concerning spark ignition engines is a trending issue, where top-down strategies to force manufacturer compliance with federally mandated emissions standards has been evaluated and legally attempted (Banks, 2015). Hearing protectors are evaluated under laboratory conditions specified by the American National Standards Institute in ANSI S3.19-1974. OSHA's noise standards (29 CFR 1910.95(j)(2) and 29 CFR 1926.52(b)) require that personal hearing protection be worn to attenuate the occupational noise exposure of employees to within the limits shown in Tables G-16, G-16a, and D-2 (OSHA; shown in appendix A).

4.2. Regulatory Standards for Carbon Monoxide

It is important to understand another separation of intent with regard to federal regulation involving Class III through Class V handheld spark-ignition engines. EPA regulations are understandably directed toward national or global level emission reductions of greenhouse gases. While a parallel and possibly complementary effect may be achieved by EPA regulation in this regard, individual worker health is not part of the stated goal.

OSHA's mission, and by extension regulations concerning worker health related to grounds maintenance have been relatively static. The Environmental Protection Agency, as the governing body charged with regulation of exhaust emissions, addresses handheld spark-ignition maintenance equipment in their Phase 2 Final Rule of March, 2000. The published OSHA Permissible Exposure Limit (PEL) for carbon monoxide exposures, Time Weighted Average (TWA) is 50ppm. The NIOSH REL is 35ppm, with a 200ppm ceiling and a 1200ppm specified IDLH level. The ACGIH Threshold Limit Value for carbon monoxide exposure is 25ppm or 28.6 mg/m3 over 8 hours (ACGIH TLV).

4.3. Regulatory standards and recommended noise levels

Both governmental agencies and public health institutes have historically recognized workplace noise conditions as a significant contributor to permanent noise induced hearing loss (NIHL). Published limits for TWA noise exposures have been widely available to employers for decades, and increased availability of hearing protective devices (ear plugs, muffs, etc) has helped reduce exposures in many otherwise hazardous job tasks.

Table 1 NIOSH 1998; OSHA 2009

Exchange Rates of NIOSH and OSHA Standards - National Institute for Occupational Safety and Health 1998; Occupational Safety and Health Administration 2009. According to each governing body, a person can safely be exposed to each decibel level for its corresponding time without risk of NIHL. For example, according to the OSHA standard, a person can withstand an environment with sound levels at 95 dBA for four hours. After four hours they are at risk for NIHL. NIOSH maintains that a person is safe in a 95 dBA environment for less than one hour.

NIOSH Standard	
Sound level (dBA)	**Duration (Hours: Minutes: Seconds)**
82	16:00:00
85	8:00:00
88	4:00:00
91	2:00:00
94	1:00:00
97	0:30:00
100	0:15:00
103	0:07:30
106	0:03:45
109	0:01:53
112	0:00:56
115	0:00:28
118	0:00:14
121	0:00:07
124	0:00:03
127	0:00:01

OSHA Standard	
Sound level (dBA)	**Duration (Hours: Minutes: Seconds)**
85	16:00:00
90	8:00:00
95	4:00:00
100	2:00:00
105	1:00:00
110	0:30:00
115	0:15:00
120	0:07:30
125	0:03:45
130	0:01:53
135	0:00:56
140	0:00:28
145	0:00:14
150	0:00:07
155	0:00:03
160	0:00:01

Table 2: ACHIH allowable exposure (without hearing protection) at a given noise level ACGIH allowable exposure (without hearing protection) at given noise level

Duration Per Day (Hours)*	Sound Level (dBA)
16.00	82
8.00	85

6.00	86
4.00	88
3.00	89
2.00	91
1.50	92
1.00	94
0.50	97
0.25	100

A careful examination of the OSHA Standard for Noise Induced Hearing Loss will contrast sharply with the NIOSH and the ACGIH TLV’s list for allowable sound level exposures. To understand the context of these similar tables, it is critical to have an awareness of three issues: (1) how ear protection actually functions, (2) the common confusion with how reduction ratings are calculated, and (3) how to realistically calculate an exposure after factoring in the NRR rating of the ear protection.

Commonly encountered professional grade handheld power equipment in the production environment produces levels between 85 dBA and 120 dBA, depending on equipment type and throttle actuated engine rpm (Table 4).

5. Noise Exposure Effects

Stated within the OSHA table: "OSHA's experience and the published scientific literature have shown that laboratory-obtained real ear attenuation for HPDs can seldom be achieved in the workplace. To adjust for workplace conditions, OSHA strongly recommends applying a 50% correction factor when estimating field attenuation. This is especially important when considering whether engineering controls are to be implemented (OSHA Appendix IV:C)

Using this direction, we can establish that a tool producing 106 dBA at full throttle would only be allowed a TWA dose duration of 3 minutes and 45 seconds, with unprotected ears.

Allowing that most grounds maintenance workers have ear protection available to them, we will predict a NRR rated 32 foam ear plug is used. Per the OSHA formula, the calculation uses the original NRR rating, then subtracts (7) dBA, and then divides by 2 for the recommended 50% corrective safety factor. (32-7=25/2=12.5NRR. This results in the anticipated exposure of 106 dBA being reduced to 93.5dBA. Again, referring to the least stringent standard, the allowable OSHA dBA TWA for a 93.5 dBA sound level is just over 4 hours. Using the NIOSH chart the same sound level allowance would only support working in these conditions with the identified PPE for less than 1 hour.

5.1. Carbon Monoxide Effects

Interviews with 8 full-time individual grounds maintenance workers stated that summertime work shifts are regularly 8 hours or longer, weather and light permitting (Schenck, personal communication; 2015). Unlike noise, which is easily sensed by all in proximity, carbon monoxide is an elusive hazard. It is odorless, tasteless, colorless, and non-irritating, and because of this, it is able to be present in significant concentrations in an airspace yet completely undetected by humans lacking CO monitors. At levels in and around the PEL, it is unlikely that any human awareness could predict or find acute symptoms of its presence. The gas acts as a chemical asphyxiant, bonding to the oxygen carrying hemoglobin in blood with an affinity for the bond 200 times that of its competitor molecule, oxygen. Because of this, persistent exposure to a low level of carbon monoxide may lead to a 50% saturation of hemoglobin (Casarett and Doull, 2013). A low level exposure results in the binding of carbon monoxide and produces stabilization of the hemoglobin molecule in the high-affinity "R" conformation which compromises oxygen delivery to the tissues (Casarett and Doull 2013). This may occur as low level exposures of carbon monoxide (sub-IDLH <1200ppm) but above the OSHA PEL (>50ppm).

Table 3: Carbon monoxide concentrations and observed effects. (Greiner 1997)

Carbon Monoxide Concentrations & Observed Effects	
(ppm)	
200	Maximum recommended workplace exposure (NIOSH). U-L listed detectors must sound a full alarm within 35 minutes. Time to alarm varies with manufacturer, with some manufacturers electing to sound the alarm more quickly. Slight headache, tiredness, dizziness, nausea after 2-3 hours, might be life-threatening in long exposure (Bacharach). Abortions and lower birth rates in pigs (Carson).
400	U-Listed detectors must sound a full alarm within 15 minutes. Time to alarm varies with manufacturer, with some manufacturers electing to sound the alarm more quickly. Frontal headaches within 1-2 hours, life-threatening after 3 hours, maximum parts per million in flue gas under AGA test guidelines.
500	Often produced in garage when a cold car is started in an open garage and warmed up for 2 minutes. (Greiner, unpublished, 1997),
800	Dizziness, nausea and convulsions within 45 minutes. Unconsciousness within 2 hours. Death within 2-3 hours. Maximum air-free concentrations from gas kitchen ranges (ANSI)
1,600	Headache, dizziness, nausea within 20 minutes. Death within 1 hour. Smoldering wood fires, malfunctioning furnaces, water heaters, and kitchen ranges typically produce concentrations exceeding 1600 ppm.
3,200	Concentration inside charcoal grills (Greiner, single example). Headache, dizziness and nausea within 5-20 minutes. Quickly impaired thinking. Death within 30 minutes.
6,400	Headache, dizziness and nausea within 1-2 minutes. Thinking impaired before response possible. Death within 10-15 minutes.
12,800	Death within 1-3 minutes.
35,000	Measured tailpipe exhaust concentration from warm carbureted gasoline engines without catalytic converters (Greiner, unpublished field studies, January 1997).
70,000	Typical tailpipe exhaust concentrations from cold gasoline engine during the first minute of a cold weather start. Concentrations decreased to 2 ppm after 17 minutes of running (Greiner, unpublished field studies, January 1997).
100,000	Smoke often reaches 10% (Ellerhorn). In less than one minute carboxyhemoglobin levels reach toxic levels of 75% COHb (Ellerhorn).
Notes:	10,000 ppm (parts per million) = 1% by volume Individual responses vary widely and are affected by respiration rate
Source:	Thomas H. Greiner, Extension Agricultural Engineer Department of Agricultural and Biosystems Engineering Iowa State University August, 1997

6. Further Literature Review - Ototoxicity

The sampling effort results (Figure 5) of higher than anticipated concentrations of carbon monoxide prompted further research into the consequences of chronic low level carbon monoxide exposures. This included toxicological review of CO's effect within the human, as well as a wider net thrown to assess a broader range of knowledge and/or published data on the observed effects on humans with low level but chronic CO exposure.

Brazilian researchers in 2015 published an evaluation of 52 industrial fisherman, 61.5% of which were found to be with audiograms below normal, with characteristics of noise induced hearing loss (NIHL) and tinnitus reported by 46.1% of the fishermen (Zeigelboim et al. 2015).

Referring to chronic CO exposures of 30 consecutive days or more, the researchers noted toxic effects including insomnia, headaches, fatigue, decreased physical capacity, dizziness, vertigo, ataxia, mental impairment, nausea, vomiting, visual disturbances, hearing disorders, respiratory diseases, and other less frequent effects (Zeigelboim et al 2015).

As consideration was given to the apparent and previously unrecognized elevated levels of carbon monoxide within the regular workspace of the grounds maintenance handheld tool user, the ranked stressors of an extended duration elevated noise environment and now OSHA PEL breaching carbon monoxide concentrations, a new concern emerged.

Research into low level (sub IDLH) carbon monoxide exposures generated 8 reviewed studies where CO exposure was linked to hearing loss, and "good evidence" was found to associate CO exposure to an impairment of hearing (Campo 2009).

Ototoxicity of carbon monoxide is believed to be a consequence of effective oxygen deprivation within the cochlea (Fechter, Thorne, Nutall 1987). Further, US based researcher Laurence Fechter reported studies from 1987, 1988, and 2000 where "carbon monoxide has potential to disrupt intrinsic antioxidant pathways or to enhance reactive oxygen species generation producing permanent hearing loss in the presence of noise. In the presence of pro-oxidant chemical agents, we demonstrated that even mild noise can yield oxidative stress leading to the death of sensory receptor cells for sound, the outer hair cells, and subsequent permanent impairment of auditory function" (Fechter; Pouyatos 2005).

7. Research Methods- Noise and Carbon Monoxide

7.1. Noise Assessment

In anticipation of the obvious hazards, noise and exhaust inhalation, the noise portion was straightforward to quantify based on (3) factors:

- Range of sound level measurement through the tools functional power band
- Duration of exposure
- Predicted consistent distance from noise point source to operator's ears. (Measurement distance from source to ears was assigned by anticipated position of each tool during standard use.)

7.2. Sampling Equipment

The 3M Quest EG5 Noise dosimeter was considered and ultimately rejected as the selected method of noise assessment, recognizing that any method of sampling, even TWA noise dosimetry, represents in the variable field setting simply a day's snapshot of true working conditions. While long term dosimetry studies can eliminate much of the abstract variability, this was not practical for the time and resources available for the study. Variabilities in terrain, throttle use, work scope, etc. result in inherent baseline variance for noise dosing. It was recognized that the sound levels measured at idle, ½ throttle, and full throttle would provide a useful approximation of sound level range. A Direct-Read sound level meter (Quest 2400) was utilized to conduct readings and establish a "worst-case scenario" based on real-time sound pressure levels.

Measurements were collected and logged with real-time direct-read gas and sound level meters. A 3M Quest EG5 dosimeter was available and considered, but was eventually passed over in favor of assessing potential conditions rather than accumulated dose. The Quest model

2400 sound level meter was chosen to provide real time direct-read of sound levels, and levels were collected in the "A" scale.

7.3. Calibration

Two types of gas monitor were selected to provide direct read measurement of CO concentrations: The Sensit Gold CGI 4 gas monitor configured to read concentration amounts of carbon monoxide (CO), hydrogen sulfide (H_2S), oxygen (O_2), and lower explosive limit (LEL) of the aggregate sample. The Honeywell Lumidor MicroMax 4 gas monitor was also used to provide redundant assurance of readings and account for potential sensor interference. The Honeywell unit was also configured to read the concentration levels of CO, H_2S, O_2, and LEL. Calibration of the Quest 2400 sound level meter was performed using a 3M Quest Technologies CQ-10 calibrator. The meter was calibrated at 114 dB at 1000Hz both pre-sampling and post sampling.

Both the Sensit and Honeywell Lumidor gas monitors were calibrated using non-expired calibration gases supplied by Sensit and ESP Precision Gas Mixtures.

7.4. Sampling Methods

Due to the inherent variability of outdoor work and inconsistent weather, direct read instruments were chosen to measure "worst-case" scenarios rather than a complex attempt to quantify actual dose. Some value could be gained from a properly designed dosimetry assessment, but in light of the time and resource constraints, the direct read "worst case" method had a better means of establishing how the equipment could generate both sound and gases unmitigated by weather conditions. For that reason, sampling times were selected with calm winds and temperatures within 10 degrees of 60F.

Engines were fueled with fresh fuel and each engine started and allowed a 6-minute warm-up cycle prior to any sampling to avoid cold condition emissions error.

The noise measurement sampling location considered the point source of sound power measurement to be each tool's exhaust port, and this was confirmed through area measurement attempts to be the highest available location of peak dB measurement. To best approximate the distance between the exhaust port and the ear, an average distance was identified for each tool's typical operating position relative to the worker. This average distance was used to locate the sound level monitor relative to the tool, and data were gathered for each tool using three throttle positions; idle, ½ throttle, and full throttle. Measurements were recorded based on the throttle positions for each tool. Distance from port to ear for all tools except the handheld leaf blower was measured and resulted in a mean of 20." This distance was increased to" to account for more typical position in the case of handheld leaf blowers.

Measurement of carbon monoxide concentrations was measured in the breathing zone of worker holding the tool in a standard operating position. Acknowledgement must be made to reflect the outdoor location of tool use and sampling, where local atmospheric conditions may result in significant fluctuations of measured concentration, especially dependent on prevailing wind velocity and consistency of direction relative work movement. Using the same assigned representative distance for breathing zone, and ranging in angles directly above the exhaust port to 45 degrees horizontally offset, data were recorded based on the throttle positions for each tool.

8. Results

Sample Results for each tool's dB(A) at three throttle positions. Results from direct read sound level sampling confirm the predicted noise levels, with chainsaw peak sound level measurement in excess of 121 dBA at full throttle. Common measurements were attained for all equipment in excess of 100 dBA at standard working load rpms. Noise and CO sampling results are presented in Tables 4 and 5.

Table 4: Sound Level Measurement Results (dBA)

Equipment Type	Make	Model	idle (dBA)	1/2 throttle (dBA)	Full throttle (dBA)
String Trimmer	Stihl	FS 80	88.7	94.8	103.4
Backpack Blower	Stihl	BR 400	86.4	96.8	108
String trimmer	Honda	GX 35	77.1	92.1	104.2
Edger	Echo	PAS 266	82.2	93.8	107.4
Chainsaw	Stihl	MS200T	88	99.2	108.2
Chainsaw	Husqv	394XP	92	114	121
Handheld Blower	Stihl	BG85	83.7	91.6	96.5
Hedge Trimmer	Stihl	HS81R	85.1	98.9	106.3
Brush Cutter	Echo	SRM410	86.5	94.6	105.8
Brush Cutter	Stihl	FS360	89.6	95.8	109.5
Pole saw	Stihl	HT 131	84	91.4	102.8
String Trimmer	Honda	GX35(2)	77.5	95.5	101.7

Table 5: Carbon monoxide concentration sample results measured at 3 different throttle positions

Equipment Type	Make	Model	CO idle in ppm	CO 1/2 throttle (ppm)	CO Full Throttle (ppm)	Peak reading (ppm)
String Trimmer	Stihl	FS 80	59	185	278	1645
Backpack Blower	Stihl	BR 400	55	128	390	1886
String trimmer	Honda	GX 35	28	69	240	874
Edger	Echo	PAS 266	19	29	89	293
Chainsaw	Stihl	MS200T	38	76	148	310
Chainsaw	Husqv	394XP	168	341	552	1798
Handheld Blower	Stihl	BG85	37	42	85	621
Hedge Trimmer	Stihl	HS81R	81	94	157	1630
Brush Cutter	Echo	SRM410	74	142	283	1484
Brush Cutter	Stihl	FS360	119	238	672	1950
Pole saw	Stihl	HT 131	45	118	130	580
String Trimmer	Honda	GX35(2)	46	132	181	1490

Figure 3 offers an illustrated approximation of potential concentration values present during times of greater than 1/2 throttle tool use of a string trimmer. These values represent what concentrations might be found during typical use in similar conditions. Variables due to wind, temperature, and local cover due to tree canopy, brush density, grass height may all significantly contribute to concentrations found.

Results from direct read carbon monoxide sampling far exceeded the PEL in every case, and quite easily revealed exposures more than twice the ACGIH TLV for carbon monoxide. The variability of engine speed, terrain, work loading, wind speed, etc. may all significantly influences a dosing evaluation. Pure dose establishment is beyond the scope of this inquiry, and would need longer range measurements to achieve a clearer reading.

9. Discussion

It is interesting and potentially concerning that both peak noise levels and permissible carbon monoxide levels found during sampling were easily able to breach the published 8hr TWA dosing limits for the OSHA permissible exposure limits. To be clear, the simple presence of stressor, even in concentrations well exceeding an exposure threshold, does not provide causal evidence that TWA PEL’s are being breached. The study does however lend support to the likelihood that this profession may be a high-risk candidate for breach of exposure thresholds.

A thorough understanding of the grounds maintenance workload and work duration practices leads one to further conclude that it is highly likely that some combination of site, tools and work practices create conditions for workers to significantly exceed published exposure limits.

This inquiry generated certainly more questions than it answered, although the effort, observation, and consideration of relevant factors provide useful foundations and clues for future investigation. It is clear that both the worker in the field, the manager in the office, and the manufacturer of the tooling all play a role in communicating information related to realistic equipment use, the duration of shift exposures, and the selection of equipment, design, controls, and PPE in order to effectively and safely address these hazards.

When considering the potential hazards facing the grounds maintenance worker, including exposure to tools, the worksite, the acute physical stressors are readily apparent and have potential to overstate their relative hazard. More involved research would be beneficial to providing guidance on future control strategies. Due to the alarmingly high CO levels reported in this manuscript, further evaluation, considering both short term and long term exposures, should be conducted. These issues justify a call to raise awareness and participate in a response solution.

9.1. Limitations

The author acknowledges plainly that a simple local atmospheric measured concentration of CO does not establish TWA dose threshold breaching. The inherent difficulties of concentration measurement in an outdoor setting are many, and the solutions few and sometimes crude. However, even those who would select long term colorimetric diffusion tubes as a means of quantifying CO dosing are still only grabbing a selection of dates throughout a widely variable season. It is difficult to make demonstrably effective engineering control decisions based on arguably deficient datasets. Variability of equipment, throttle use, CO production, weather, site changes will create variance where none was expected. Fortunately, the data supporting CO as a concerning toxicant are widely known and supported, and increasing. Also fortunate is that the levels are potentially so high, that action to reduce them may come more quickly than a fight over minute decimal points and politically governed PELs.

10. Conclusions

In full disclosure, the author has worked with spark ignition handheld grounds maintenance tooling for many thousands of hours in a professional capacity. My permanent hearing loss was diagnosed in 2009, in spite of diligent use of best available PPE. I wear hearing aids in both ears every day. This study was both revealing and confirming of a wide variety of in-depth hazard considerations related to professional grounds maintenance work. It is clear that information existed in scientific journals at least as early as 1997 that a link between carbon monoxide exposure and ototoxicity was being revealed (Morata 2003). It is also clear and acknowledged by OSHA that the real world limitations of hearing protection devices have been recognized as insufficient to protect a worker over an 8 hour period without additional active monitoring or administrative controls. Without efforts to effectively disseminate this information to workers who are affected, it remains likely that occupational hearing loss will continue within the population of grounds maintenance professionals.

- Efforts within my role as an Industrial Hygiene & Safety Manager at Montana State University will continue specifically in support of ongoing awareness Training
- Hearing Conservation Program
- Continued Data collection in support of CO exposures and Ototoxic links

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Appendix A: Methods for Estimating HPD Attenuation

https://osha.europa.eu/en/tools-and-publications/publications/literature_reviews/combined-exposure-to-noise-and-ototoxic-substances,

Methods for Estimating HPD Attenuation

The actual effectiveness of any individual hearing protector cannot be determined under workplace conditions. However, OSHA's noise standards (29 CFR 1910.95(j)(2) and 29 CFR 1926.52(b)) require that personal hearing protection be worn to attenuate the occupational noise exposure of employees to within the limits shown in Tables G-16, G-16a, and D-2, respectively. Hearing protectors are evaluated under laboratory conditions specified by the American National Standards Institute in ANSI S3.19-1974 (OSHA's experience and the published scientific literature indicate that laboratory-obtained real ear attenuation for hearing protectors can seldom be achieved in the workplace).

- Appendix B: Methods For Estimating the Adequacy of Hearing Protector Attenuation provides information on how to determine the adequacy of hearing protector attenuation using the noise reduction rating (NRR) of a given hearing protector.
- Use the following formulas to estimate the attenuation afforded to a noise-exposed employee in a work environment by muffs, plugs, or a combination of both.
    - A common method used for **single protection** (either muffs or plugs) is as follows

      1. Determine the laboratory-based noise attenuation provided by the HPD. This is referred to as the Noise Reduction Rating (NRR) and is listed on the packaging.

      2. Subtract the NRR from the C-weighted TWA workplace noise level, as follows:

      Estimated Exposure (dBA) = TWA (dBC) - NRR

      If C-weighted noise level data is not available, A-weighted data can be used by subtracting a 7 dB correction factor from the NRR, as follows:

      Estimated Exposure (dBA) = TWA (dBA) - (NRR - 7)

      Example:

      TWA=100 dBA, muff NRR=19 dB

      Estimated Exposure = 100 - (19-7) = 88 dBA

    - For **dual protection** (ear muffs and plugs are used simultaneously) use the following:

      1. Determine the laboratory-based NRR for the **higher** rated protector (NRR_h).

      2. Subtract 7 dB from NRR_h if using A-weighted sound level data.

      3. Add 5 dB to the field-adjusted NRR to account for the use of the second hearing protector.

      4. Subtract the remainder from the TWA as follows:

Estimated Exposure (dBA) = TWA (dBC) - (NRR_h + 5) , or

Estimated Exposure (dBA) = TWA (dBA) - [(NRR_h- 7) + 5]

Example:

TWA=110 dBA, plug NRR=29, and muff NRR=25 dB

Estimated Exposure = 110 - [(29 - 7) + 5] = 83 dBA

- OSHA's experience and the published scientific literature have shown that laboratory-obtained real ear attenuation for HPDs can seldom be achieved in the workplace. To adjust for workplace conditions, **OSHA strongly recommends applying a 50% correction factor** when estimating field attenuation. This is especially important when considering whether engineering controls are to be implemented. The equations above would then be modified as follows:

    - Single Protection:
      Estimated Exposure (dBA) = TWA (dBC) - [NRR x 50%], or

      Estimated Exposure (dBA) = TWA (dBA) - [(NRR - 7) x 50%]

    - Dual Protection:
      Estimated Exposure (dBA) = TWA (dBC) - [(NRR_h x 50%) + 5] , or

      Estimated Exposure (dBA) = TWA (dBA) - {[(NRR_h - 7) x 50%] + 5}

Appendix B: Reference

Reference	
A-Weighted Sound Level, L (decibel)	**Duration T (hour)**
80	32.0
81	27.9
82	24.3
83	21.1
84	18.4
85	16.0
86	13.9
87	12.1
88	10.6
89	9.2
90	8.0
91	7.0
92	6.1
93	5.3
94	4.6
95	4.0
96	3.5
97	3.0
98	2.6
99	2.3
100	2.0
101	1.7
102	1.5
103	1.3
106	0.87
107	0.76
108	0.66
109	0.57
110	0.50
111	0.44
112	0.38
113	0.33
114	0.29
115	0.25
116	0.22
117	0.19
118	0.16
119	0.14
120	0.125
121	0.110
122	0.095
123	0.082
124	0.072

125	0.063
126	0.054
127	0.047
128	0.041
129	0.036
130	0.031

In the above table the reference duration, T, is computed by

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